Neuroscience of Human Movement
Department of Multidisciplinary
Indian Institute of Technology, Madras

Lecture – 18
Muscle force production

Welcome to this class on a skeletal muscles part 3 are called as Muscle force production and various kinds of muscle force production as part of the neuroscience of human movement course.

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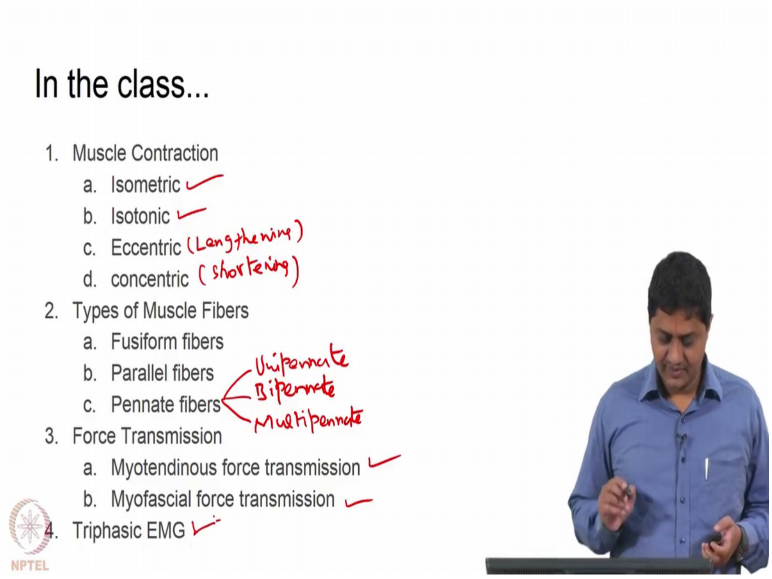

So, what we will we be looking at in this class? We will be looking at types of muscle contraction, we will be talking about isometric force production metric contraction, isotonic, eccentric, or what are called as a lengthening contractions and concentric contractions or what are called as shortening contractions are related to each other.

Types of a muscles fusiform muscles, parallel fibered muscles and pennate muscles, differential actually pennate muscles has two three types depending upon classification. Unipennate, bipennate or if there is more than one angle sometimes it is also called as multi pennate or bipennate can also be sometimes called as multi pennate depending on the type of classification, and how is force transmitted.

So, force can be transmitted to through tendon to bone so, in that case we call it as myotendinous force transmission or it can be transmitted to neighboring fascial issue.

And, then to aponeurosis and then from aponeurosis to the tendon in an indirect way, then we call it as myofascial force transmission. And, how to produce quick fast actions and how an electro monographic recorded for quick fast actions will look like so that is the triphasic EMG part.

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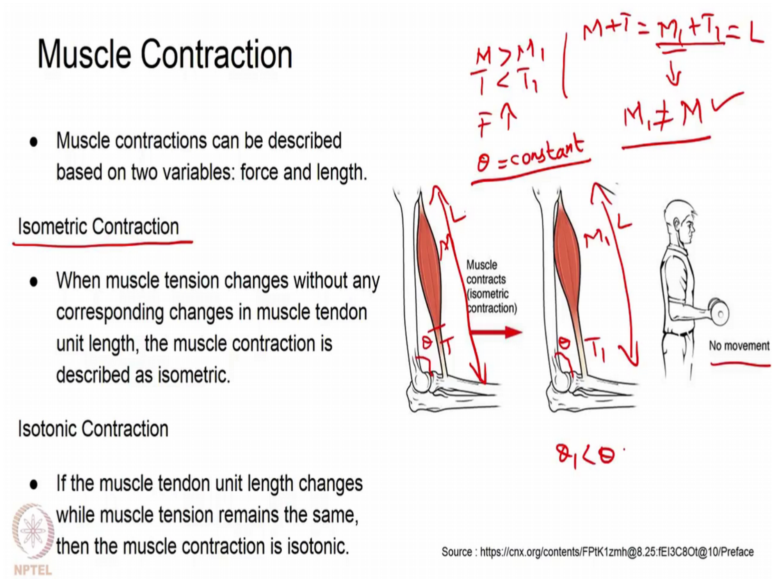

So, there are several things; that are of interest for us muscle force and muscle length right. And we already have seen the relationship at least in brief we have described that relationship between muscle length and muscle force. And important criterion is the following so, let me remind you of this criterion that was mentioned. If the muscle tendon unit length remains a constant iso means equal, metric means length is it not. So, which length is going to continue to be equal, that is the question in this case it is not the muscle length, but rather the muscle tend an unit length this is what we mentioned.

Let us look at this in some greater detail; let us remember the points the following points that the muscle is the force producing element in the muscle tendon it and the tendon just transmits the force from the muscle to the bone, movement happens when the bone moves relative to another bone that is what we see as movement. Now, if you consider a case where the muscle is shortening so in this case so now that is the tendon length and that is the muscle length for example, initially.

And let us say that the joint angle is some theta, now the person is you know asked to increase the force produced by the muscle without changing theta; what will happen is that theta will remain theta. Whereas, T will become a new T which is going to call at call that as T 1 and M will become M 1. Let us remember that M is greater than M M 1 is it not. Whereas, T is lesser than T 1 or in other words what is going on is that the tendon is contractile is made of contractile proteins, it is mainly made of collagen.

When the muscle is pulling on it the tendon is going to get pulled and it is going to elongate, actually depending on the muscle depending on a particular tendon: the amount of elongation can be relatively large very large amount of elongation the tendons can take without suffering; you know physical damage without suffering material damage, they can take relatively large trees. This is an important property of tendons, this is the reason why we do not get injured although; we perform many impact exercises. And many of the impact related injuries are also related to tendon injuries.

So, basically the tendon gets turned if you over load that if the tendon gets turned then that is results in some sort of injury. So, the tendon can get pulled much longer so T 1 becomes greater and M 1 becomes smaller than the earlier case, in that case what will happen is at the force will increase; force increases in this case, but what happens to theta itself theta remains a constant between the two cases

So, this is the key; that the joint angle does not change there is no movement, that is produced, movement is not there yet force is changing. This is the case of isometric contraction isometric force production, the case in which them this change happens in such a way that M plus T is equal to M 1 plus T 1. This is the key, this is the isometric part there or in other words that length remains the same, that length I am going to call as L for example, so that L remains the same that is the isometric part.

So, in this case M plus T equal to M 1 plus T 1 still a problem that I cannot solve you know uniquely, because there are number of variables, there are number of combinations of M 1's and T 1's that could still satisfy this is not. There are there could be different M 1's and T 1's that will still sum to M plus T. So, there will be so, I could change this lengths at different levels are so; that means, the force can also be changed over the range of M 1. Let us remember that the force length relationship in the muscle is related to not the muscle plus tendon unit length, but rather just the muscle length.

M 1 alone defines force length relationship not M 1 plus T 1, because of this reason as M 1 changes as a combination of M 1 plus T 1 being kept constant force will change. So, I could keep changing the force without changing the length so isometric contraction, but it is usually in some cases non technical people, people who do not; come from the background may say that the you know at constant muscle length force is changed.

This is not true people, who students of this course must be able to distinguish the difference between constant muscle length and constant muscle plus tendon unit length. In this case what becomes what remains constant is not the muscle length it is not M in particular important to note that M 1 is not equal to M this is not true ok. M 1 is not equal to M or M 1 this inequity is true, M 1 is not equal to M is always true in the isometric force production cases this is critical this is important to realize this. So, you should never make the mistake of saying that you know: when you say isometric force production you should never make the mistake of saying that the muscle length remains the constant.

What remains constant is the muscle plus tendon unit length so these are the trick questions that you get in examinations. So, when people ask like what is isometric for force production? Immediately we should be in the position to say that muscle plus tendon unit length remains a constant without change in theta, without change in the joint angle, without change in without any movement that is being produced. Of course, when there is movement what will happen that is the question, if theta become something say if theta becomes theta 1 which is less than theta then; that means, I am flexing this; that means, I am bringing the two bones closer to each other.

In that case what happens that means you know not only the not only the muscle length changes actually the everything changes is not; actually the theta changes then there is movement this case is no longer true. A case in which I am changing the theta, but I am keeping the force produced by a muscle constant; dso, in other words so the force produced can also be called as tension or tone in the muscle, it is a misnomer. So, sometimes people you know wrongly refer this as tone refers to some amount of tension in the muscle.

So, the this traditionally this terminology continuous in this field, this is the reason why we call and equal force contractions as isotonic contractions, case in which muscle length changes. So, in this case the muscle plus tendon unit length changes, but the tension or the force produced by the muscle remains approximately the same. So, in that case the contraction is called as iso tonic contraction.

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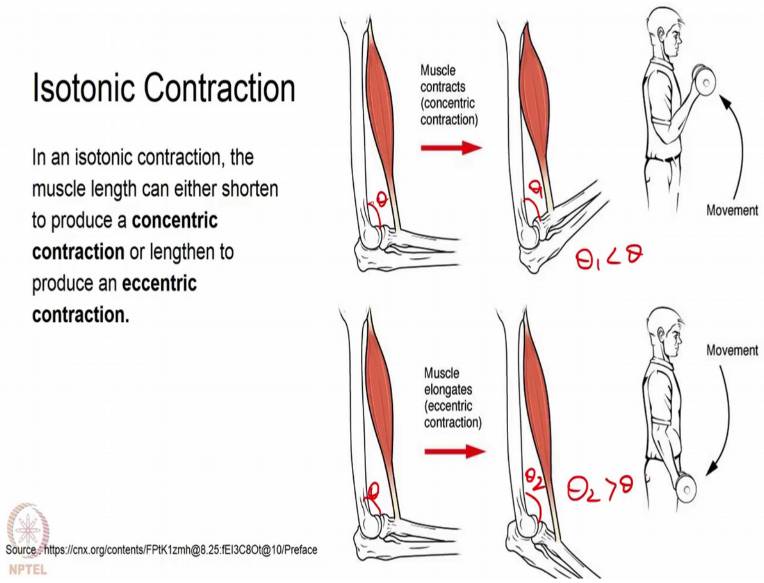

So, in that case what will happen is that you know so one when would you do that so, suppose I am having a dumbbell and then let us up let us assume that this is a dumbbell and I am performing relatively steady force production with that not doing too fast well in that case the force will quickly change and then drop, but relatively steady curls bicycle right. In such cases the force will remain approximately a constant it is not exactly a constant. Approximately a constant and that can in that case remember that you know theta was this much here now that is theta 1 and lets note and that is theta and that is theta 2 is it not.

In that case you know theta 1 is less than theta in this case theta 2 is greater than theta. So, I could do either right, I could keep it at as angle I could extend or I could keep it at an angle and flex. When the muscle is shortening and it is producing a force like in this case so in this case what happens is that the muscle is shortening it is length is reducing is it not, earlier it was some length L now it is L 1 where L 1 is less than L right.

So, in that case the muscle is shortening and it is producing a force a case in which muscle length is shortening is called as concentric contraction or shortening contraction of the muscle. The case in which the muscle length increases, but the force is being produced right.

In this case muscle along it is like in this case where you know; the muscle length was earlier L and this is sum L 2. Now, in this case let us remember that L 2 is greater than L, L is it not. Now, in this case the length increases and that kind of contractions in which the muscle length increases is called as eccentric contractions or lengthening contractions ok.

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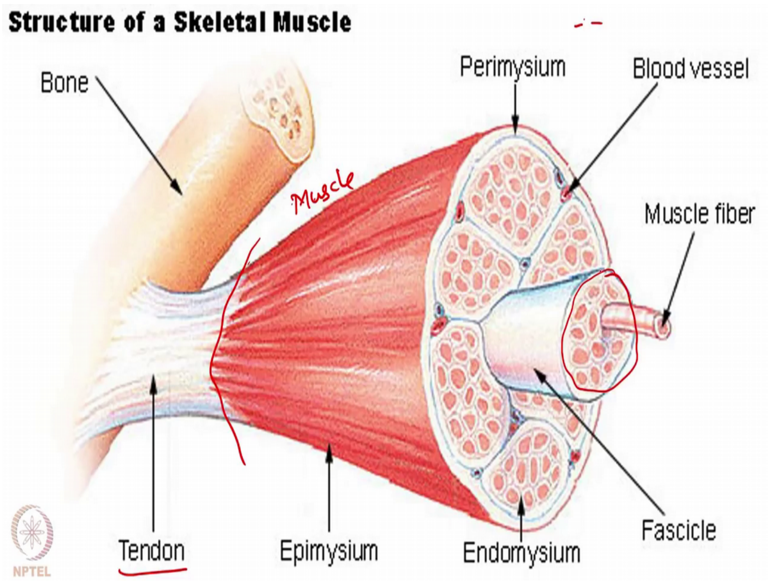

Now, let us remind ourselves of the case of how the forces getting transmitted to the bone and what is the structure of the; skeletal muscle. It is look at the case so until this point you have what is called as muscle. So, the whole thing is called as a muscle and this part is called as tendon. Now what is the fundamental difference the difference is that the tendon just transmits the force and it is not neurally innervated.

The muscle produces and transmits force and is neurally innervated right. How is this controlled we have seen so, within the muscle there are several bundles primary bundle, secondary bundle, tertiary bundle, etcetera. And within the smallest bundles there are fascicles that contain arrangements of muscle fibers and within the fascicle there are several muscle fibers. And important point to note is that the fibers within the farcical are parallel to each other, but the fascicles themselves are not parallel to each other.

So, at the higher level of hierarchy there could be no parallel arrangement, but within the fascicle all the fibers are parallel to each other; in the previous classes what we have seen that the force produced in a sarcomere gets transmitted serially within the myofibril several that is a serial addition of force. And across fibers there is parallel addition of force and there is also going to be parallel audition of force across fascicles, across bundles and so, on and so, forth depending on how much the muscle is activated.

Now if some force is produced by this muscle it is going to be transmitted to the bones so, this is the bone is it no, to the bone via this tendon. Now, this is a simple case in which the muscle converges into the tendon that attaching to the bone in this kind of tendons are also called as external tendons ok. The case where the tendon attaches to the bone they are called as external tendons, but there may be other cases.

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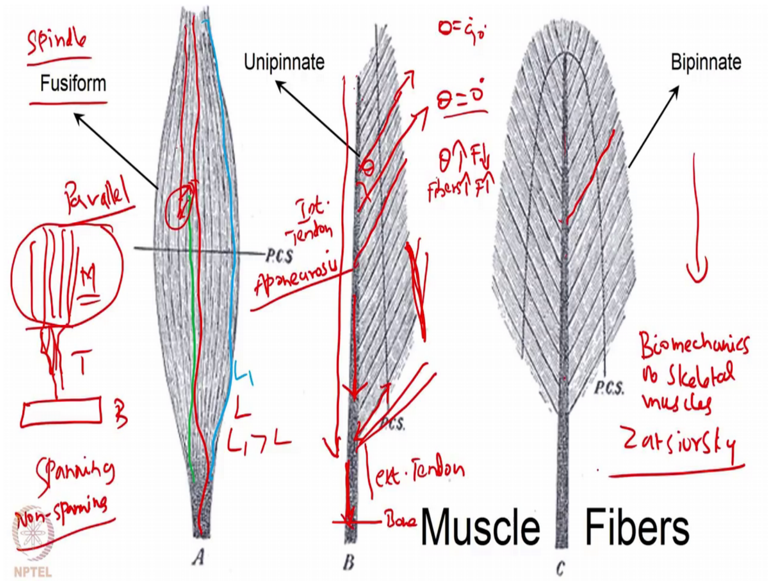

What are the other cases let us take a look at those in a particular case several fibers so; here each inclined fiber each inclined line represents a fiber. And they all attached to a tendon and this tendon goes on to attach to a say a bone here for example. Now note importantly that the thickness of this tendon increases as you come down is it not, as you come down you note that the thickness of the tendon increases.

This tendon that collects force from multiple fibers and passes on to the external tendon this part is called as the external tendon this part where the force from multiple fibers are summed to transmit to the external tendon is called as the internal tendon also called as aponeurosis technical term force produced by fibers is along the air line of action. So, individual fibers pull in that direction is it not. So, that is the direction of force, but the muscle force is in that direction is it not.

So, what does this mean? This means that not all the force that is produced by the fiber is going to get converted into muscle force. Muscle force is what is felt at the tendon, at the bone, bone tendon junction, whatever is the force that is felt the muscle line of action of force is in that direction whereas, the muscle fiber line of action of forces is in that direction is it not.

So; that means, only a component of the fiber produced force gets transmitted to the bone. And obviously, that would change as a function of that is it not as a function of theta as theta suppose for example, if theta equal to 90 degrees none of the if theta is 90 degree none of the force; will get transmitted to the bone is it not. So, what is preferable in this case, is to have theta very small is it not; so, what would that that ideal case b, when theta equal to 0 degrees is it not. So, or in other words when I have fibers parallel to the tendon so suppose that is the tendon and fibers are all parallel to the tendon.

So, suppose that is the tendon and that is the muscle and let us say that is the bone. In this case you see theta equal to 0 degrees and all the fiber forces gets converted into muscle force. What is the difference between fiber force and muscle force, fiber force is that force that is produced by individual muscle fibers muscle force is the force exerted or force felt by the bone right.

So, this case this special case has a special name this is called as this is actually the parallel fiber muscle, this is the case where you know all the fibers are parallel to each other and attached to the tendon directly. So, in that case all the fiber force will get transmitted faithfully. This is a relatively rare case, this is you know more prevalent why, why would evolution prefer this model, why? Because I could pack more number of fibers in such arrangements in such complex geometries I could pack many more fibers then I would be able to do that.

If I were to pack the same number of fibers assuming that all individual fibers produce the same amount of force if I would like to pack more fibers I will require greater amount of volume to pack this is it not. This volume I cannot offered, because body size can only be so much I cannot keep increasing the body size indefinitely, because of limitations, because of constraints in the body size it turns out that I am interested in coming up with more complex architectures, more complex geometry, more complex morphologies.

In which I am able to you know compromise I am able to find a tradeoff between morphology between the structure and the amount of force transmitted; obviously, this arrangement is less efficient, anyone with basic physics knowledge will be able to say that well that is a very poor arrangement, because as I am producing more force. But, not all the force gets stands for in other words I am exhorting more energy than what is actually getting used very poor arrangement.

But evolutionarily biological system need not work from necessarily from an engineering perspective. What this is trying to do is oh I am trying to pack more volume and I am trying to why would we need more volume, because the total force that is needed would be greater total force that can be produced by a pennate muscle would be greater. And there are other arrangements for example, this arrangement of a bipennate muscle where there are two angles in which this is attaching, again note importantly that as the as the internal tendon goes on to attached to the external tendon. As the aponeurosis goes on to attach to the external tendon look at how the aponeurosis becomes thicker as you go down.

So, if you are going down you can note that the aponeurosis is becoming slow slightly thicker with each this ok, that are more complex morphologies not discussed. The other case is the case, of spindle shaped muscle or the fusiform muscles, in this case what happens are this is the usual muscle example that is given by many people. So, in this case what happens is that there are fibers whose length is equal to the muscle length and then there are fibers whose length is greater than the muscle length. So, because this is responses slight arc if I take this I am going to draw this with a different colour just for clarity right.

If I take that blue line and straighten it and I am going to find the length L 1 and if I take the red line which is in the middle and straighten it I am going to find L anybody with anybody can save from intuition that L 1 will be greater than L. So, in this case and there are several L's along the way so, as you go as we move from the center of the muscle to the periphery of the muscles the length of the individual fibers keeps changing. And in this case again not all the force that is going to be transmitted to the bone but is not just that there are there is more complexity involved in this case also what also happens is some fibers start from here and end there.

And then there are other fibers that start from here and end there, there are fibers that start from one end to the from one end and end at the other end this kind of fibers are called as a spanning fibers. These span the entire length of the muscle so, they are called as spanning fibers and then the case, where some fibers start at one end, but end in the middle of the muscle do not continue till the end of the muscle the other end it does not go for example, these two, these two cases right.

A question is how can force be transmitted in such a case, because if this mail, if this fiber is getting activated by the neuron, then the circumfuse in that are going to contract due to excitation contraction coupling and some force is going to get produced. Then the, this force is going to be useful only if it is going to get transmitted to that point right, is that how is that achieved is a question.

This is still; the subject of intense research, what is known at least is the following that there is parallel force transmission some amount of force gets transmitted in these directions not all. So, this kind of force transmission that happens from fibers to neighboring facial tissues is called as myofascial. So, this type of fibers that end in the middle are called as non spanning fibers ok.

And this type of force that gets transmitted from fibers to neighboring facial tissues are called as myofascial force transmissions, as you age what would happened to the pennation angle would be a question suppose; the why is that even important? Because you see pennation, pennation is present in all people in all muscles in many muscles right.

So, there is there is this feature that is present everywhere, but the angle could change as a function of age, exercise etcetera, how does the change pennation for example; would increase or decrease depending on these features, what would happen with age right what would happen is usually what is desirable? Is to have the pennation angle relatively small closer to parallel fiber is it not.

That is the aim because we want to get maximum force that is transmitted that is going to happen when theta is close to 0 or when it is closer to the upper neurosis. So, that happens with age, but that happens due to a different problem right, that happens because of because many fibers diode are become oftened and because of that reason these become straight end, these become closer to the upper neurosis with age.

When you lift weights perform strength training let us say you are a bodybuilder you are trying to perform exercise, what you are doing is your adding more and more fibers. You are adding you are adding more volume you are adding more bulk to the muscle; you cannot do that indefinitely because of space constraints.

So, what will then happen in the is in the in such cases is that the pennation angle will become greater as you are exercising pennation angle will become greater note; that means, is aging good or not exercising good, no there are multiple things it is not just pennation angle the total amount of force that is produced produces, because of the number of fibers. So, there are two things one is theta: as theta increase you know force contribution are the component of force that is getting transmitted reduces. And as the number of fibers increases, force increases, but it turns out that the number of fibers that increase during due to exercise is much greater than the reduction in force due to increase in theta.

Which is why if we exercise if you able to lift heavier weights as you go along right, but it does cause a reduction in force or an increase in theta ok. There is more details; there is I have just covered the basics of this topic there is more detail those who are interested can verify, can check biomechanics of biomechanics of skeletal muscles zatsiorsky. You can check this book and more detail and more morphological structures on the various possibilities are all presented and important point is to note is that you know from the control view point we are interested in the neuroscience of movement more than the morphology of muscles.

Where this is structure this is structural, but we are more interested in control right, from the control view point it is important to note that I do not know the theta I do not know the change in theta, I do not know what component is myofascial, I do not know many things with respect to muscle force. So, it is; very difficult for the system to specify forces, it would not be possible for the system to know so, many fibers I will need to recruit and if I recruit so many fibers exactly. So, many mili Newton of forces are so many Newton's are whatever.

So, many kilo new tons of force will be produced that something that is going to be very difficult for the system are controlled if there is a controller to predict why? Because I do not know the thetas by the way it is also possible that the thetas will vary as a function of the fibers we are only shown some cases between; fibers that could be you know variability theta is actually, I have I have the picture is drawn in such a way that theta is the same across these.

But here is at least more complicated case where there are to two thetas, but there can be multiple thetas. In multi pennate case so, I do not know in defuse form case I do not know how much what proportion of the fibers are actually non spanning and what proportion of the non spanning fiber force is going to get transmitted through the myofascial transmission.

So, without knowing all those things it is very difficult for me to recruit fibers in such a way to ensure that I get a specific amount of force yet, humans are able to perform very dexterous and well controlled movements it remains a mystery how they are doing it, that is a purpose of this course to clarify that mystery to some mystery.

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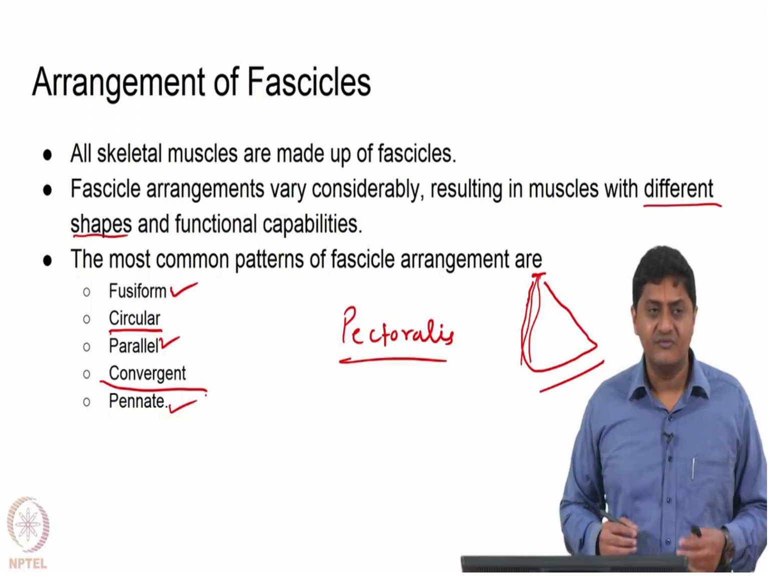

Also we have discussed these farcical arrangements very considerably, because I mention this area earlier that within the fascicle fibers are parallel to each other, but fascicles need not be parallel can be can result in very complicated architecture.

So, muscles with very different shapes very different functional capabilities are there. A particular case is the case of the conversion muscles, example; is the chest muscle or the pectoralis muscle shortly called as the pec muscle right. This muscle is a conversion muscle or what has what is called as the triangular muscle in that case one part of the muscle is broad whereas, the other part of the muscle is thin

So, this is this length is different from this length see the chest muscle; this is the architecture the fibers are running like this all right. So, these type of muscles are called as convergent muscles, more complicated structures are available circular muscles that are found in the mouth an important and well controlled muscles.

So, if I am speaking out specific alphabets that is due to the amount of orifice the amount of the size of the orifice varies and as the air moves out specific alphabets are specific words are phonemes are spoken out very well controlled precisely controlled muscle. How does the geometry affecting these cases?

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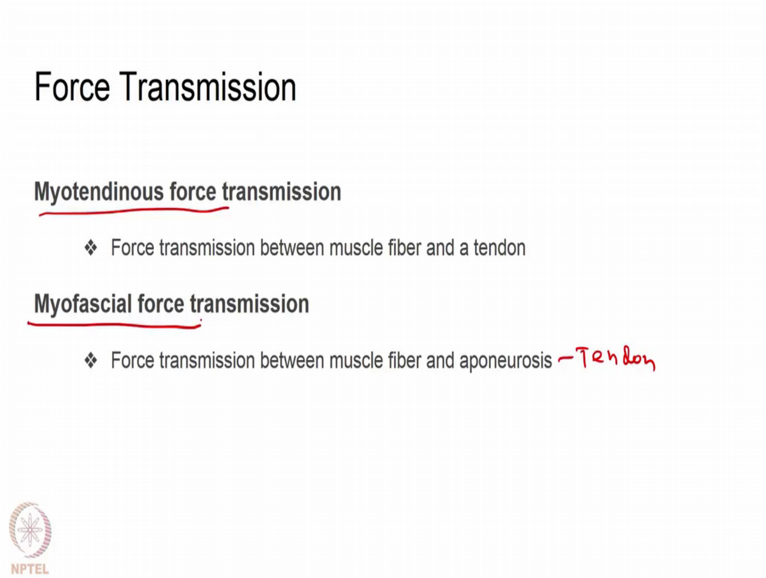

So, several of these are present and we have seen these cases; fusiform, parallel, pennate, which are the most common or the more common cases. And, as I said when force gets transmitted from a fiber to a tendon, that is straight forward myotendinous force transmission. When force transmitted is from one fiber to an aponeurosis, from an aponeurosis to a tendon this is basically myofascial force transmission let us remember that we do not know what proportion of force gets transmitted.

We may not be able to exactly estimate theta from this picture if I am giving you this picture and ask you to estimate theta then it is possible for me. It is for me to estimate and if I am telling the force produced by each fiber then it is possible for you to estimate what is the force that Is going to you know that is going to be achieved at that point, at that point.

That anyone that anyone with basic physics and engineering mechanics knowledge can do, but from the controller view point it is not reasonable for me to expect that the system, that the controller somehow knows what the theta is or the thetas are there maybe multiple thetas.

And only if I know all the thetas I am going to be able to know what is the force produced by that muscle or which fibers to recruit. So, it is a relatively more complicated problem then what appears and even more completely is this case, how much of this transmission is happening in parallel. So, control cannot be so precise, control cannot be the control in the engineering sense.

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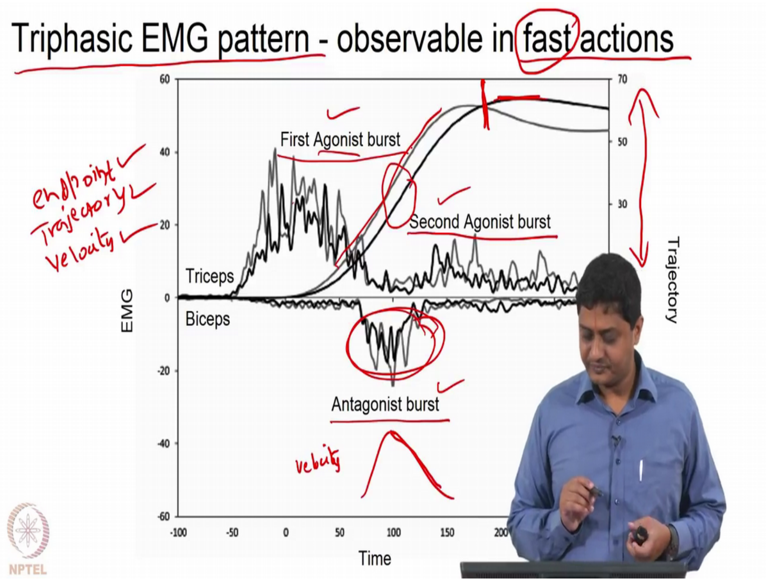

Another case is the case of; how displacement is produce a smooth displacement is produced in relatively fast actions. Suppose I making fast reaching actions suppose I am doing that right, important to note is that the keyword here is fast; in fast actions I am interested in two things. I am interested in reaching to a particular destination so what is shown here is the trajectory. So, that is the trajectory and what is shown on these with the dark lines is the is one; is the agonists burst and the and the light lines is another type of you know activity.

So, if I am producing a fast action usually there is co activation of both the agonist and the antagonist, we define what is an agonist and what is an antagonist from a for a particular action. One muscle can be agonist and the muscle on the other side that prevents, the details movement of this; the details this movement can be considered antagonist for example, in this case; where considering say elbow flexion or elbow extension of the case may be suppose for elbow flexion biceps can be considered as the agonist and the triceps is the antagonist.

So, triceps opposes flexion it tries to prevent flexion, simultaneously both of these are co activated why are this co activated remains a million dollar question. Why do we have to do this I could individually control one muscle and present relatively accurate control signals to one individual muscle and then get the same output is that even possible.

From engineering viewpoint that might make sense, but; however, in the biological system this is hard to achieve. So, I am interested in producing a fast action right so, in that case I have to control the velocity. If I allow one to one muscle to supersede the other muscle, then what will happen is that I may miss the target. And this has consequences important consequences, suppose I want to catch that cup for example, right if I over shoots it is entirely possible that I could drop this cup. So, such actions are not desirable so, you want to stop at a particular point right and if it is a fast action that you are interested in performing let us say you want to quickly pick up a pen.

In such cases you are your movement should be controlled to multiple aspects of your movement must be controlled not just, not just the end point there are several things end point, you have to reach the end point it is critical. You do not want to miss the end point, you do not want to over shoot you do not want to miss the end point so that is important. Obviously, trajectory; is trajectory control important to some extent trajectory control is important another thing is velocity.

So, several things; come into the picture several parameters that are not immediately obvious come into the picture in to control of this. So, the first agonist burst includes sometimes co activation of the antagonist. After sometime to at the middle of the displacement here at around not exactly at the middle, approximately and the middle of the antagonist here there is going to be an antagonist burst ok.

These results in you know slowing down why is this important? Because at around this point if this and if these are the displacement curves what would my velocity curves look like so, here the velocity will start increasing and at some point reduced, because why does this reduce well actually ideally I am this going to look something like this, this is the velocity curve is it not. So, why because, I have to slow down because I have to stop here, it is a different target; obviously, this is the net displacement. So, many MM's are so many centimeters or whatever this is the displacement, this is the net displacement that is achieved.

But I want to at this point I want to stop if I have to stop then I have to slow down here. So, to slow down I am activating the opposing muscle, while switching off the muscle that is for a brief period. The muscle that is producing the movements thus effectively slowing down this trajectory that slows down. And then again there is a second agonist burst that brings this to a stop. So, this case where there are three phases the first agonist burst, the antagonist burst followed by the second; agonist burst there are three phases, this is called as a triphasic EMG pattern important to note is that this may not be observable in relatively slow actions.

So, if the action is you know a relatively slow it is possible that there will be no antagonist burst. That anybody can guess if I am moving making this movement relatively, slowly it may not be necessary for me to you know slow down, because I am already slowly moving slowly the movement to movement control may still be sufficient with just one burst.

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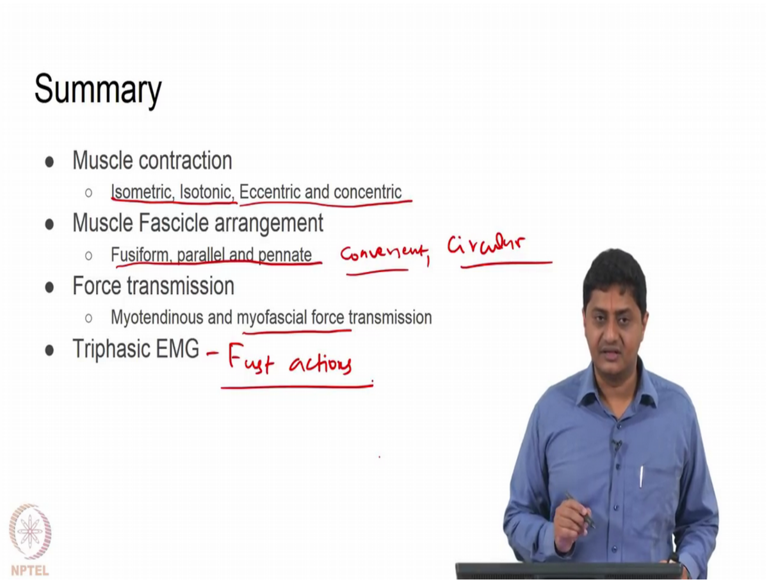

So, in this class what we have seen is isometric, isotonic, eccentric and concentric contractions and different types of muscle fiber arrangements fusiform, parallel, pennate and we have also seen other cases other special cases like; convergent; circular etcetera. And what happens with those at least we have introduced those topics and how force gets transmitted to a tendon directly sorry so myotendon is for transmission and how it gets indirectly transmitted to the tendon or myofascial; for transmission and we have seen in the case of a triphasic EMG in fast actions.

So, with this, we will end this class we come to the end of the lecture on skeletal muscles.

So, thank you very much.